OPTIMIZATION OF MACHINING PARAMETERS IN MULTI-PASS TURNING

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By

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Certificate

It is certified that the work contained in the thesis entitled "Optimzation of machining parameter in multi pass turning", by **Brijesh Kumar Tiwari** has been carried out under my supervision and this work has not been submitted elsewhere for a degree.

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Abstract

This present work describes a procedure to calculate the machining conditions, such as the cutting speed, feed rate and depth of cut for turning operations with minimum production cost or the maximum production rate as the objective function. The optimum number of machining passes and the depth of cut for each pass is obtained through the computer programming and the same has been used to determine the optimum values of machining conditions for each pass based on the objective function criteria. Production cost and production time values are determined for the identical work piece and tool material combination and for same input data, the initial diameter being different. In the optimization procedure, the objective functions are subjected to constraints of maximum and minimum feed rates and speed available, cutting power, tool life, deflection of work piece, axial preload and surface roughness. Total input is given to the program which produced optimum result for minimum cost and maximum production rate and suggests the total number of optimal passes along with the corresponding speed, feed and depth of cut in each pass. By 3-D graphical representation optimum point for each pass is shown in this work which verifies the result.

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(Brijesh Kumar Tiwari) August, 2002

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NTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Establishment of efficient machining parameters has been a problem that has confronted ıanufacturing industries for nearly a century and still remained the subject of many studies.)ptimum machining parameters are of great concern in manufacturing environments, where conomy in machining operation plays a key role in market competitiveness. In the past, when oth labor and machine costs were relatively low, cutting conditions were primarily related to atisfy such factors as accuracy and surface finish, rather than on economic grounds. However, vith the increased use of sophisticated and high cost numerically controlled machines, economic actors as well as technological ones must be taken into consideration. The optimization rocedure of a metal cutting operation is however complex. This is due to the various constraint cting on the process as well as the general complexity of the metal cutting operation.

The primary objective in optimizing machining condition is to produce products with low cost and high quality hence machining economics is a very important consideration to achieve such objectives.

Machining economics involves the optimum selection of machining condition such as cutting speed, feed and depth of cut, since these parameters directly affect the cost, productivity and quality of products. Practical constraints are introduced to consider the permissible ranges of speed, feed and cutting tool life.

1.2 Criteria Of Optimization In Turing

Optimization can be done by three criteria:

- Maximum profit rate
- Minimum cost
- Maximum production rate

Optimization of production rate is important when we want production of product large. A large rate of production may result in a better return, and therefore it is also useful to investigate the conditions leading to the highest possible rate of production. The maximum production rate can be achieved if the total time required per piece is reduced to a minimum.. For mass production this criteria is efficient for small jobs but number of jobs is high.

Optimization of cost is important for those industries where small number of jobs is produced but jobs are larger.

The total cost of a part can be written in the form:

Total cost = cost of jigs and fixture/batch + process adjusting & return cost/piece + loading and unloading cost/piece + machining cost/piece + tool changing cost/piece + tool cost/piece

The total time of a part can be written in the form:

Total time=setting time/piece + process adjusting & return time/piece + loading & unloading time/piece + machining time/piece + tool changing time/piece

Arrangement Of Passes

ıchining can be performed by

- Single pass
- Multi pass with equal depth of cut in each pass
- Multi pass with different depth of cut in each pass

Single pass machining can not be always performed due to higher force on the tool and the l breaks very often. Hence multi-pass machining is normally used to avoid such problems. ılti pass machining with different depth of cuts in each pass is more economical than the one h equal depth of cuts in each pass [4] although both the processes may sometimes show the ne results. Hence optimization is done in multi pass with different depth of cut in each pass.

The optimum value of number of passes and the corresponding speed, feed and depth of cut each pass is obtained in a multi pass process. Total number of passes, depth of cut, optimum tting speed and feed rate for each pass is determined through a computer program discussed in apter 2. The methodology of the problem is to minimize the objective function related to oduction time or production cost by finding the optimum values of decision variables $X(v,f)$ bject to constraints, namely, tool life, cutting power, cutting force, tolerances, axial work ılding preload and surface roughness. The region bounded with these active constraints is called asible region.

Any change in the constraints will automatically change the optimum point and the value f the objective function. For example, when the tool life constraints are relaxed, which can be one by reducing the number of parts machined with a single tool within a certain time interval, nly surface roughness and cutting power constraints will be active and the intersection point of

these two constraints generates the optimum point. Surface roughness constraint could also be relaxed by increasing the R_a value and in this case diametrical tolerances would become active.

In the present work, same tool is applied for finish pass and rough pass for total depth of cut. Total depth of cut is divided into sections and each section is treated as a single pass operation by taking the constraints of maximum and minimum feed rate and speed available, cutting power, tool life, deflection of work piece, axial pre load and surface roughness into consideration. Optimum values of machining parameters are found by using a computer programming technique which calculates the minimum cost value and corresponding optimum feed rate and cutting speed values.

After applying this technique to each possible section and storing them in a matrix form, dynamic programming technique is applied to minimize the objective function. A suitable value of number of passes and a suitable value of depth of cut for each pass is selected according to the constraints and total depth of cut, for both rough and finish passes simultaneously.

1.4 Literature Review

A lot of research work has been carried out on optimization of machining in turning. A number of theoretical models were proposed by a number of researchers in the field of optimization of machining in turning.

Shin and Joo [1] have done a model for the optimization of machining conditions in a multi pass turning operation. In this paper optimization has been done for both roughing and finishing operations and dual optimization of cost functions for each sub problems was pursued. The preventive tool replacements strategy used in practice is incorporated. Machining idle time (idle tool motion time) was also regarded as a variable. After practical constraints are established, optimization was carried out using the dynamic programming method.

Gupta et al [2] have proposed a new approach for the determination of the optimal subdivision of depth of cut. The total production cost minimization was achieved by summation of the minimum costs of individual rough passes and the finish pass was independently minimized. The optimal subdivision of total depth of cut was obtained using an integer-programming model. The resulting subdivision of depth of cut yields a lower minimum cost than that obtained by using the commonly practiced strategy of having minimum depth of cut in the finish pass and removing the remaining depth of cut in number of rough passes of equal size.

Meng et al [3] described the optimum cutting conditions in turning. Objective criteria were selected as minimum cost or maximum production rate. The method used a variable flow stress machining theory to predict cutting forces, stresses, etc, which were then used to check process constraints such as machine power, tool plastic deformation and built-up edge formation. A modified form of Taylor tool life equation where the constants were determined using the machining theory had been employed in predicting tool life for the optimization procedure. The obtained results indicate that the described method was capable of selecting the appropriate cutting conditions.

Cakir & Gurada [4] have reported a work on optimization. In this paper first the optimum number of machining passes were evaluated and the depth of cut for each pass was obtained through the dynamic programming technique and optimum values of machining conditions for each pass were determined based on the objective function criteria by search method application to the feasible region. In the optimization procedure the objective function was subjected to constraints of maximum feed rates and speeds available, cutting power, tool life, deflection of work piece, axial pre load and surface roughness.

Hinduja et al [5] has described a procedure to calculate optimum cutting conditions for turning operations with minimum cost or the maximum production rate as the objective functions. For a given tool/work combination, the search for the optimum was confined to a feed versus depth of cut region which was defined by the chip breaking constraints. Some of the other constraints, which are considered by the system, include power available, work holding, surface

finish & component accuracy. If more than one pass is necessary to rough machine a given area, the optimum depth of cut calculated for each pass may have to be modified.

Lambert and Walvekar[6] has developed a formulation of the multi pass machining operation. In this paper the author has presented N passes state variable, decision variables, objective function & stage transformation defined at each pass. Number of passes was determined first. Geometric programming was utilized to determine the values of machining variable for each pass to yield minimum production cost. The levels of speed and feed were subject to certain restrictions based on allowable values of forces, power and surface finish.

Wu and Ermer [7] have described that maximum profit is an appropriate criterion for the selection of the optimum machining conditions rather than the conventional criteria of minimum cost or maximum production rate. This concept was developed under the assumption that the empirical parameters in the tool life equation were known. A simple example was presented to illustrate the determination of the cutting speed for maximum profit by application of a fundamental economic principle that maximum profit occurs at the production rate where the marginal revenue equals to the marginal cost. The effect of the demand function, feed, cost and time parameters on the determination of the cutting speed for maximum profits were analyzed. Emphasis was given to the investigation of a range of optimum cutting speeds, instead of the theoretical optimum speed, for practical applications.

Iwta et al [8] described an analytical method applying a chance constrained programming concept to determine the optimum cutting conditions considering the probabilistic nature of the objective function and constraints. The proposed analytical method was illustrated through an application. The volume of material machined per unit of tool wear and the production cost per component were employed as the objective function to be optimized. It is shown that the optimum cutting conditions were significantly affected by the probabilistic nature of coefficients in constraints. The effect of the uncertainty of the predicted tool life in the production cost function on the optimum cutting conditions was also considered. The study further investigates the effects of the cost time parameter and allowable maximum force on the optimum cutting conditions and the resulting production cost.

Ramaswamy and Lambert [9] have developed cost optimization for a single-pass turning including inventory & penalty costs. This paper analyzed total cost optimization for a single-pass turning operation for a given feed & depth of cut taking into consideration penalty cost for due date violation and in-process inventory cost. These costs were in addition to the two cost components, viz. machine & operator cost, and tool consumption cost, which were usually considered in studies on machining economics.

Boothroyd and Rusek [10] have shown that a condition can be determined in which the profit obtained within a given period is maximized and this can be used as a single criterion. Analyses of the economics of metal machining are based on Taylor tool life relation. In this paper economics by the maximum efficiency criterion (maximum rate of profit) was a convenient means of comprising between the conditions for minimum cost and for minimum production time in a machining process.

Hati and Rao [11] described the mathematical programming techniques, applied to determine the optimum cutting parameters of machining operations. Three objectives, eg, the cost of production per piece, the production rate, and the profit, were considered for optimization. The different constraints that arise during the machining operation were also considered. As some parameters involved in the process may not be purely deterministic, a probabilistic model was set up for the cost of production per piece and the production rate. After converting the probabilistic model into an equivalent deterministic model, the mathematical programming techniques were applied and the result obtained was compared with those of the deterministic model. A sensitivity analysis with respect to the cost parameters was carried in the case of cost of production per piece.

Ermer and Kromodihardio [12] have concluded that the single-pass turning was optimum if the operation was only restricted by the highest allowable feed, which was not the most general case. The more likely situation will be that the operation was subjected to such practical constraints as available horsepower, desired surface finish, and minimum tool life, max.

Permissible feed, and a range of allowable cutting speeds. Single-pass operation was not always the most economical or the most productive under such practical constraints. It can be shown that two passes, or sometimes even three passes, could be cheaper or took less production time. The objective of this work was to illustrate when multipass turning was optimum and what ratios of rough to finishing depths of cut would give the optimum result. The optimizing was determined by geometrical programming combined with linear programming. This mathematical approach can handle as many constraints as required, and any combination of them can be tight or loose at the optimum solution. Several examples were given to demonstrate the application of method and the advantage of the process optimizing technique.

Yellowley [13] described machining economics in case of two-pass turning operation. This paper has shown that the concept of equivalent chip thickness allows the development of general rules for the selection of cutting conditions in the two-pass turning operation. The paper was mainly concerned with the formulation of general guidelines for the subdivision of total depth of cut. The results indicate that, in most cases, the cost was minimized when the depth of cut in the initial pass was as great as possible.

Yellowley and Gunn [14] described optimal subdivision based on optimal chip thickness and maximum depth of cut. In this paper main emphasis was given on the torque and power constraints and not on surface finish or other parameters. In this paper the authors have attempted to decouple the problem of depth or width of cut subdivision from the overall problem of specification of cutting conditions in multi-pass roughing operations. While the authors have suggested that the guidelines presented in this paper might be used to significant advantage, there are specific cases where the guidelines will not necessarily lead to an optimal subdivision of total depth or width of cut in roughing operations.

Gopalkrishnan and Faiz [15] described the design and development of an analytical tool for the selection of machine parameters in turning. The problem was to determine values for machine speed and feed that minimize the total cost of machining; specifically the cost associated with machining time and cutting tool wear. Geometric programming was used as the basic methodology, and the solution approach for the selection of machine parameters was based on an

analysis of complementary slackness conditions and realistic machining conditions. The quality of the solution was illustrated with several examples and compared to solutions obtained by some available optimization methods. In this paper technique was simple and straightforward and indicates how sensitive the solution was to the machine power consumed and surface finish attained.

Agapiou [16] introduced a novel, rational objective function that incorporates both the production cost and total time criteria. The problem of determining the optimum machining conditions for multipass operations was investigated. The optimum number of machining passes was obtained through the dynamic programming technique and the optimum machining conditions for each pass were then determined based on the objective function. This approach could be very effectively applied to multistage machining since the optimum arrangement of the different operations could be determined by the dynamic programming method while the optimum cutting conditions for the operations in each machining stage were obtained using the method for single pass. A multipass turning process was theoretically analyzed and a computational procedure for obtaining the machining parameters was developed. Several examples were presented in order to illustrate the procedure and demonstrate the advantages of the proposed optimization technique for a multipass turning operation.

Ermer [17] introduced a more complete solution to the machining economics that took into account several constraints of the actual machining operation. The object of the work was to illustrate how a relatively new mathematical programming method, called geometric programming, can be used to determine the optimum machining condition when the solution was restricted to one or more inequality constraints. This optimizing method was especially effective in machining economics problems where the constraints may be nonlinear and the objective function of more than second degree. Furthermore, the geometric programming approach furnishes a unique insight into how the optimizing criterion was distributed among its components for a given set of input parameter values.

Aresecularatne et al [18] described the procedures used in a technologically oriented numerically controlled (NC) system to determine the optimum cutting conditions automatically

for turning, drilling, grooving, threading and parting off operations. In rough turning, the optimum depth and feed combination was determined using a direct search procedure on the allowable depth/feed region for chip control. The system determines the optimum depth of cut, feed and velocity for each pass in multi-pass turning on the basis of a user selected objective criterion and a number of technological limitations that may apply to the process, such as machine power, dynamic instability, allowable range of depths and feeds for the tool and work holding limitations, which include axial slips, circumferential slip and component throw out. A user-friendly manual option was also provided which allows the user to specify the cutting parameters. Examples were given to illustrate how these procedures determine the optimum cutting conditions. A comparison between the machining cost and time using cutting conditions obtained from handbooks was given.

Crookall [19] described the performance-envelope concept, representing the permissible and desirable operating regions of machining. The concept was developed for a particular combination of work piece and tool. Analysis of cost and time provided an economic envelope bounded by the maximum or minimum production rates, and within which a choice of near optimal was available. One objective was to utilize the flexibility, which was a basic characteristic of machining. The effect of various constraints in limiting the operating range was examined and include the machine tool in terms of range and power, and the tool work piece combination in terms of various tool failure modes, work piece rigidity and surface roughness produced. Experimental data were used to demonstrate the undesirable effects of operating near the built-up edge region, and also some aspects of the effect of the operating point on the nature and quality of the machine surface.

Iwata et al [20] have shown the probabilistic model of objective function. This paper deals with the problem of optimizing the number of passes required together with the cutting speed, the feed, and the depth of cut at each pass for a given total depth of cut to be removed from a work piece, considering both the probabilistic nature of the objective function and the constraints in the machining processes. Applying the concept of dynamic programming and stochastic programming, the problem was formulated in an analytically tractable form and a new algorithm was developed for determining the optimum value of the cutting speed, feed, depth of cut, and

number of passes. A typical example was solved to obtain the cost, minimizing cutting conditions, in a turning operation and the effect on the optimum cutting conditions of the various factors such as total depth of cut, uncertainty of the tool life, and constraints was shown.

Till now optimization of machining parameters in multi-pass turning has been done taking the constraints such as surface finish, cutting force, cutting power, cutting parameter constraints, tolerances and axial work holding preload. The formulation in all such cases has been done by either dynamic programming model or by the integer-programming model and search method. Some new constraints like cutting torque, tool thrust, tensile stress on rake face, primary shear zone temperature and temperature at tool chip interface can also be taken into account. Also some new method of formulation like FEM and programming can be used to get more accurate result.

In this work the objective function (production cost and production time) are defined optimization of machining parameter in multi pass turning is done taking the constraints surface finish, cutting force, cutting power, cutting parameter constraints, tolerances and axial work holding preload. The formulation of the problem is done by a computer program.

The second chapter of the thesis deals with the formulation of production cost and production time for turning. The third chapter emphasis on experimental set-up and procedure. In the fourth chapter result of experiments are shown and comparison is made with result obtained from program. In the fifth chapter conclusions and scope for future work are shown.

CHAPTER 2
MODELING OF TURNING OPERATION

2.1 Introduction

The minimum production cost or minimum production time criteria are most commonly used for the determination of optimal machining conditions. The various constraints for a pass are defined in terms of decision variables viz. speed, feed and depth of cut corresponding to each pass. The mathematical treatment of optimization problem requires a suitable model and solution methodology to determine the optimal machining condition viz. the optimal number of passes, speed, feed and depth of cut for each pass. For simplicity, straight turning operation of a cylindrical workpiece has been considered. The problem is to find the optimum production cost and production time within the prescribed constraints. It is assumed that, machining is always either finishing or roughing. The corresponding constraints have been identified and implemented. The next step consisted of formulating the optimization problem and developing a solution methodology. The following chapter deals with the formulation of production cost and time for turning.

2.2 Objective Function

The optimization of turning operations is realized according to two objective functions

1. Production cost, and
2. Production time

Production cost can be expressed [4] as:

Production cost$=\dfrac{C_j + C_o T_s}{N_s} + C_o(T_a + T_1) + C_o T_m + (C_o T_d + C_t)\dfrac{T_m}{T}$ (2.1)

and,

Production time$=\dfrac{T_s}{N_s} + (T_a + T_1) + T_m + T_d \dfrac{T_m}{T}$ (2.2)

Where

C_o is cost of labour and overhead (Rs/min)

C_j is cost of jigs and fixtures(Rs.)

C_t is tool cost(Rs/cutting edge)

T_s is tool set up time(min)

T_d is tool changing time(min)

T_m is machining time (min)

T_a is process adjusting and return time (min)

T is tool life

T_1 is loading and unloading time

N_s is batch size

For turning operation machining time can be expressed as

$$T_m = \frac{\pi DL}{1000vf} \tag{2.3}$$

Where

L is length of workpiece

D is workpiece diameter

And taylor's tool life equation used

$$T = \frac{K_e}{v^{\alpha} f^{\beta} d^{\gamma}} \tag{2.4}$$

Where

v is velocity in turning, in m/sec.

f is feed in turning, in mm/rev.

d is depth of cut, in mm

α, β, γ and K_e are constants

Substituting T_m and T in Eq. (2.1) and (2.2)

Production cost,

$$X_c(v,f,d) = \frac{C_j + C_o T_s}{N_s} + C_o(T_a + T_1) + C_o \frac{\pi.DL}{1000vf} + (C_o T_d + C_t)\frac{\pi.DLv^\alpha f^\beta d^\gamma}{1000vfK_e} \quad (2.5)$$

Production time,

$$X_t(v,f,d) = \frac{T_s}{N_s} + (T_a + T_1) + \frac{\pi.DL}{1000vf} + T_d \frac{\pi.DL}{1000vf}\frac{v^\alpha f^\beta d^\gamma}{1000vfK_e} \quad (2.6)$$

Since the depth of cut is constant during any elemental pass machining, the cost for any elemental pass is function of only velocity and feed.

Cost for any elemental pass

$$X_c(v,f) = K_{1c} + K_{2c}v^{-1}f^{-1} + K_{3c}v^{\alpha-1}f^{\beta-1}$$

Time for any elemental pass

$$X_t(v,f) = K_{1t} + K_{2t}v^{-1}f^{-1} + K_{3t}v^{\alpha-1}f^{\beta-1}$$

Where,

$$K_{1c} = \frac{C_j + C_o T_s}{N_s} + C_o(T_a + T_1)$$

$$K_{2c} = \frac{C_o \pi.DL}{1000}$$

$$K_{3c} = (C_o T_d + C_t)\frac{\pi.DLd_e^{\ \gamma}}{1000K_e}$$

$$K_{1t} = \frac{T_s}{N_s} + (T_a + T_1)$$

$$K_{2t} = \frac{\pi.DL}{1000}$$

$$K_{3t} = T_d \frac{\pi.DLd_e^{\ \gamma}}{1000K_e}$$

Where d_e is depth of cut for one elemental pass

Eqns. (2.5) and (2.6) show that both production cost and production time are the function of velocity (v) and feed (f).

2.3 Constraints

In real life, turning operation is restricted by various constraints listed below

2.3.1 Surface finish

Surface finish can be expressed in terms of CLA value (Ra), or peak to valley height (h). The relationship for peak to valley h in terms of feed f and nose radius r, as presented by Armerago and Brown [1969], is

$$h = \frac{f^2}{8r} \tag{2.7}$$

The peak to valley height of the finished surface should be less than its maximum permitted value (h_{max}), i.e.,

$$\frac{f^2}{8r} \le h_{max} \tag{2.8}$$

Or,

$$f \le (8rh_{max})^{1/2} \tag{2.9}$$

Where h_{max} is maximum allowable surface roughness and r is nose radius.

2.3.2 Cutting Force

Total cutting force (F_C) is approximated by the relationship [Shin and Joo, 1992]

$$F_C = K_1 f^{p_1} d^{p_2} \tag{2.10}$$

If the cutting force in turning is increased then undesirable deformation takes place along with the increase in power consumption and hence to prevent this a maximum cutting force is decided based on the following equation.

$$K_1 f^{p_1} d^{p_2} \le F_{max} \tag{2.11}$$

where F_{max} ix maximum cutting force on the tool, K_1, p_1 and p_2 are constants depending on workpiece and tool material combination.

2.3.3 Cutting Power

During machining the cutting power should not exceed the available power of the machine tool.

$$\text{Cutting power, P} = \frac{F_C V}{6120\eta} \tag{2.12}$$

Where η is efficiency of machine during cutting
On combining the Eqns. (2.10) and (2.12)

$$\frac{K_1 f^{p_1} d^{p_2} V}{6120\eta} \le P_{\max} \tag{2.13}$$

Where $P_{\max}$ is maximum power of the machine and F_c is total cutting force.

2.3.4 Parameter Constraints

Velocity, feed and depth of cut should lie between their maximum and minimum values

$$V_{\min} \le V \le V_{\max} \tag{2.14}$$

$$f_{\min} \le f \le f_{\max} \tag{2.15}$$

$$d_{\min} \le d \le d_{\max} \tag{2.16}$$

2.3.5 Tolerances

A workpiece with length-to-diameter ratio of more than 6, or a disc with small length to diameter ratio, or a thin walled section pose certain restrictions during machining. The depth of cut chosen should be such that the radial force does not cause much deflection of the workpiece. The diametral accuracy (d_T) should be less than double of maximum deflection ($\nabla_{\max}$) [Escikoglu et al., 1985], i.e.,

$$d_T \ge 2\nabla_{\max} \tag{2.17}$$

Where $\nabla_{\max}$ is given by

$$\nabla_{\max} = \frac{K_b F_r L^3}{ED^4} \tag{2.18}$$

Here E is the modulus of elasticity for work piece material and F_r is the radial force and its value may be taken as equal to the cutting force (F_C). The value of constant K_b depends on chucking and / or holding method such that 0.6 for workpiece held between the chuck and center, 1.4 for workpiece held between the centers and 2.4 for workpiece held in chuck.

Then Eqns. (2.10) , (2.17) and (2.18) give

$$\frac{2K_b K_1 f^{p_1} d^{p_2} L^3}{ED^4} \le d_T \qquad (2.19)$$

Where K_b is a constant

F_r is radial cutting force

E is modulus of elasticity of the material of workpiece

d_T is tolerances on the work piece diameter

∇_{max} is maximum deflection on the work piece.

2.3.6 Axial work holding preload

Axial cutting force must be less than the axial preload F_L. The axial force is taken as 40% of the actual cutting force. [4]

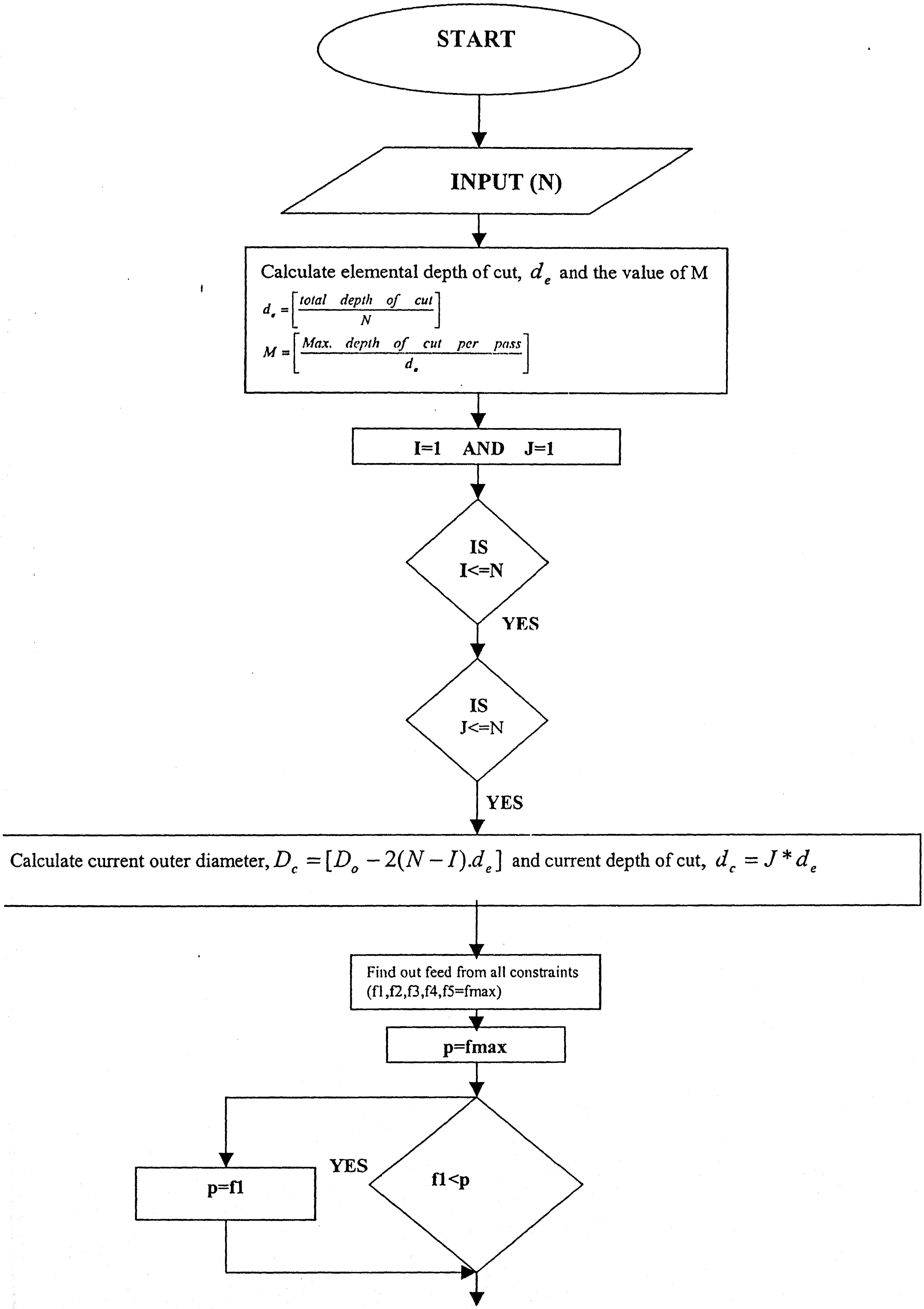
$$F_L \ge 0.4F_C \qquad (2.20)$$

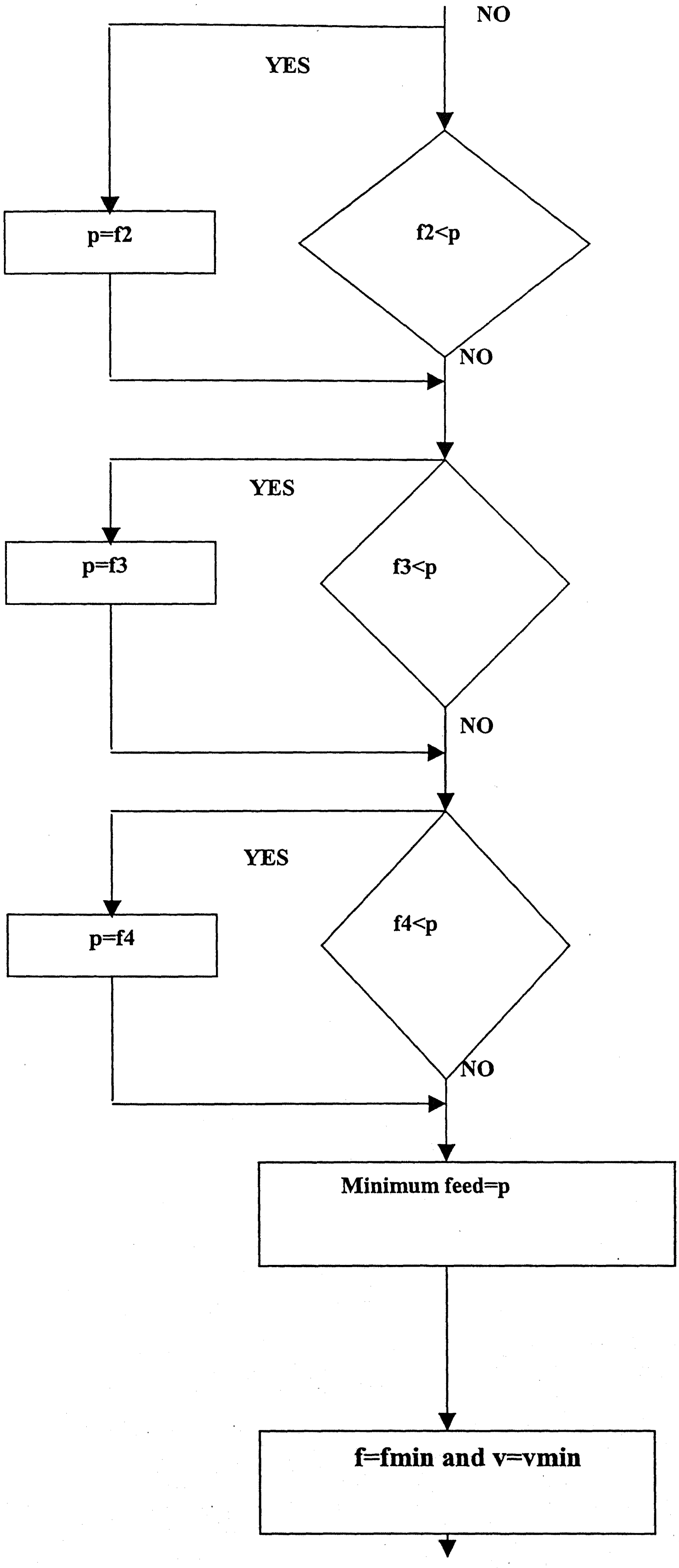
$$F_L \ge 0.4K_1 f^{p_1} d^{p_2} \qquad (2.21)$$

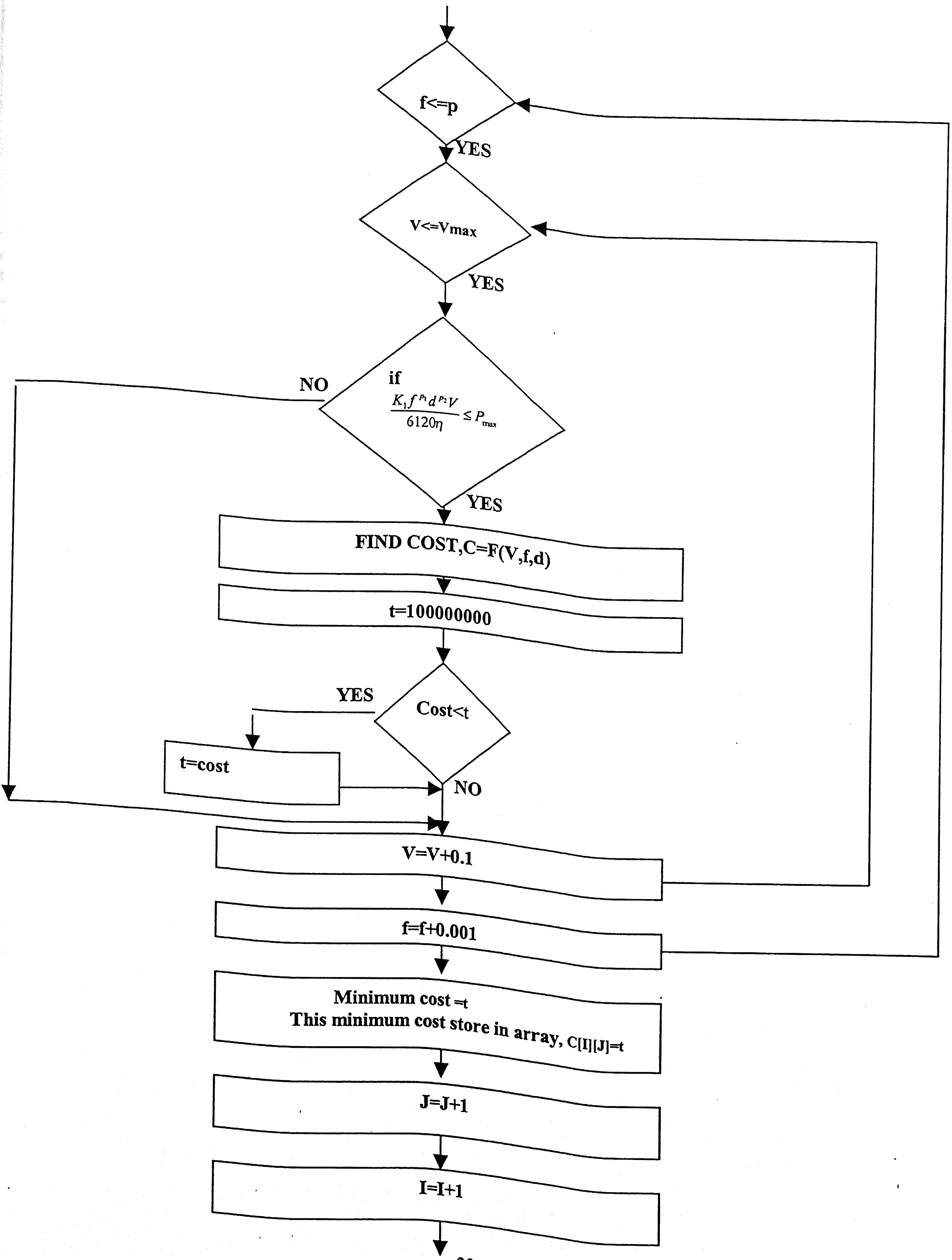
2.4 Flow Chart Of Program

Fig.2.1 shows the flowchart of the computer program developed for the optimization of production cost and production time. Data used for machining (see Annexure-1) were given to this program. This program compute total number of possible passes, minimum production cost and minimum production time.

FLOW CHART OF PROGRAM




NO
YES
p=f2
f2<p
NO
YES
p=f3
f3<p
NO
YES
p=f4
f4<p
NO
Minimum feed=p
f=fmin and v=vmin



f<=p
YES
V<=Vmax
YES
NO
if
$\frac{K_1 f^{p_1} d^{p_2} V}{6120\eta} \le P_{max}$
YES
FIND COST,C=F(V,f,d)
t=100000000
YES
Cost<t
t=cost
NO
V=V+0.1
f=f+0.001
Minimum cost =t
This minimum cost store in array, C[I][J]=t
J=J+1
I=I+1

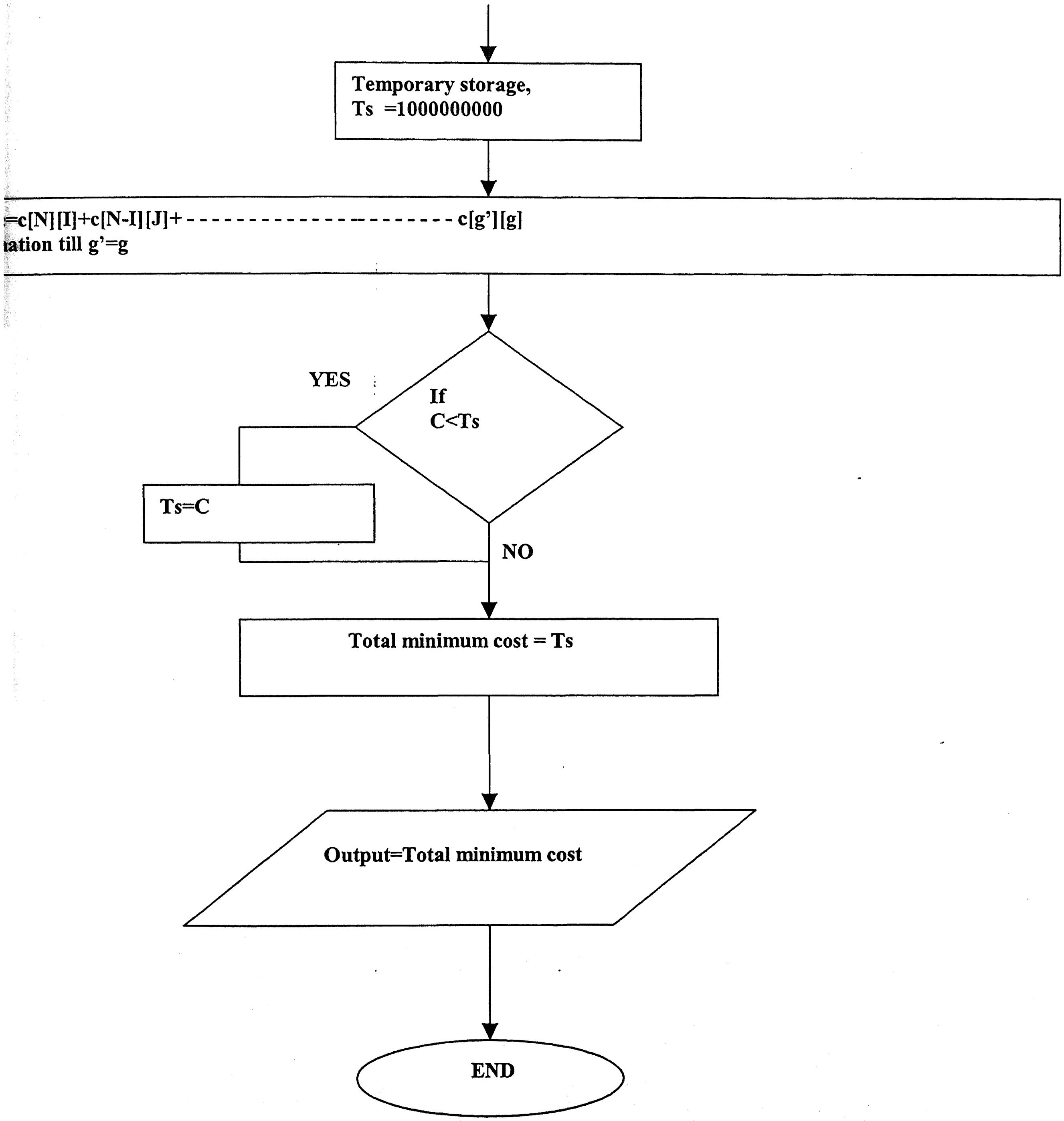


Fig.2.1: Flowchart of the computer program developed

2.5 Formulation Of Optimization Problems

First the total depth of cut was divided in N sections and then a number M, indicating maximum number of elements that can be taken at a time for turning operation was determined. After that the current outer diameter and current depth of cut for a particular element was found out. These values of diameter and depth of cut were put in constraints (Eqs. 2.9, 2.11, 2.13, 2.19, 2.21) and all the values of feed from all constraints were determined. After the feasible range of speed and feed was found out from the constraints, the values were put in the computer program, which computed the production cost and production time for each incremental value of feed and speed. These values were compared by the same program to select the optimum one for which the optimum production cost was finally calculated.

The procedure described above has been elaborated below with an example.

Example:

A cylindrical job of initial diameter D_o has to be turned to its final diameter D_f with a total depth of cut d shown in Fig.2.2.

First the total depth of cut was divided in N sections to find out d_e,

$$d_e = \left[\frac{total \quad depth \quad of \quad cut}{N} \right].$$

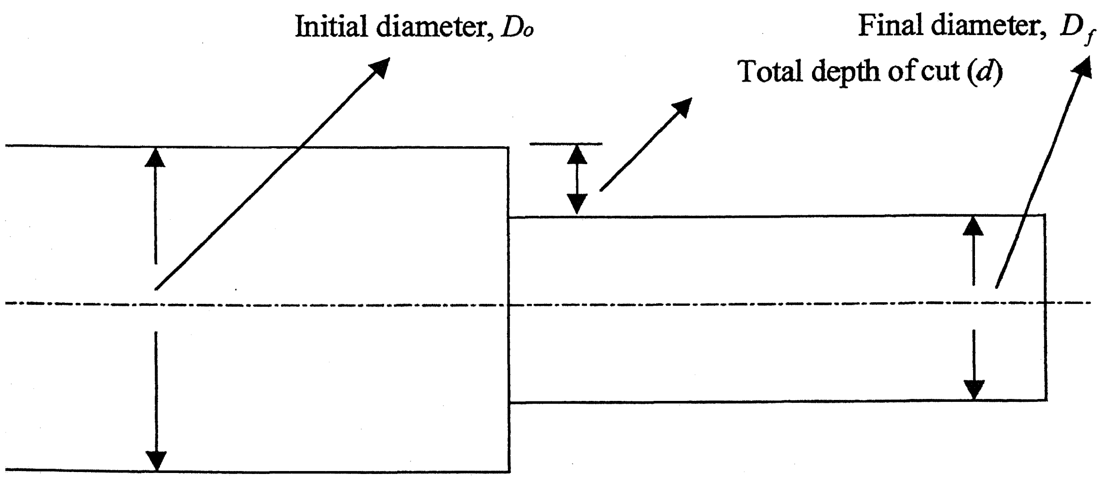


Fig.2.2: Cylindrical job after complete turning operation

After that a number M indicating maximum number of elements that can be taken at a time for turning operation was determined.

Knowing the maximum depth of cut per pass, the value of M can be determined as:

$$M = \left[\frac{Max.\ depth\ of\ cut\ per\ pass}{d_e} \right].$$

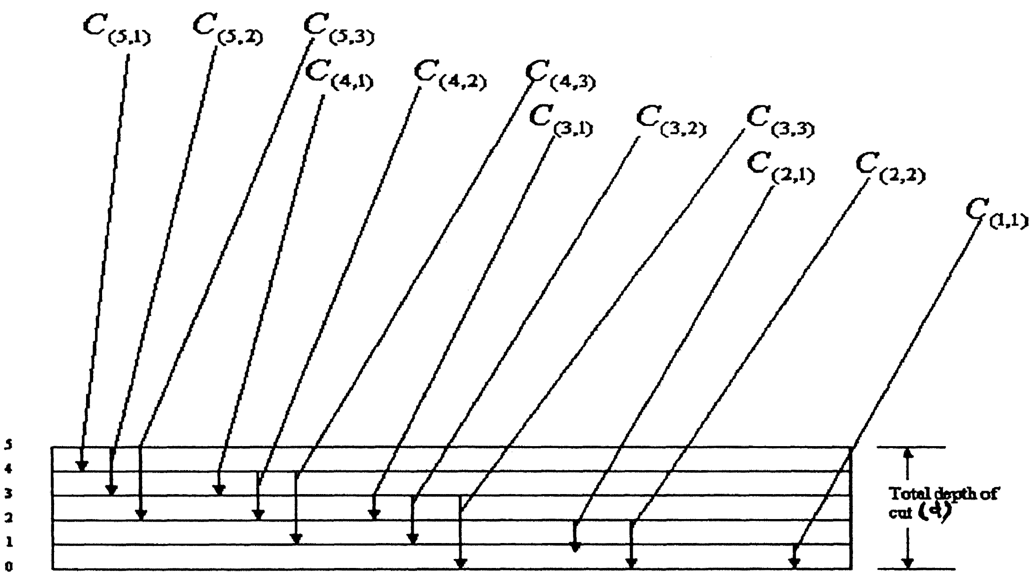


Fig.2.3: Number of option for machining

Fig.2.3 shows the number of ways the total depth of cut (*d*) can be realised.

Let, total depth of cut = 5mm,
maximum depth of cut per pass = 3mm,
and no. of sections (N) = 5,

Then $d_e = \left[\frac{5}{5} \right] = 1mm$,

and $M = \left[\frac{3}{1} \right] = 3$.

Number M indicates maximum number of elements that can be taken at a time for turning operation.

Here maximum number of elements that can be chosen at a time for turning operation is three (M=3) which is shown in Fig.2.3.

Now minimum cost was found out by taking depth of cut d_e ,$2d_e$,$3d_e$,-------- Md_e and the current outer diameter and current depth of cut were calculated along with the feed from all constraints (current diameter and current depth of cut).

Then current outer diameter $D_c = (D_o - 2.(N-i).d_e)$ and current depth of cut $d_c = j.d_e$ where D_c and d_c is current outer diameter and current depth of cut

With reference to Fig.2.3.

For cost $C_{(5,1)}$ current outer diameter is D_o and current depth of cut is d_e.

For cost $C_{(5,2)}$ current outer diameter is D_o and current depth of cut is $2d_e$.

For cost $C_{(5,3)}$ current outer diameter is D_o and current depth of cut is $3d_e$.

For cost $C_{(4,1)}$ current outer diameter is $(D_o - 2d_e)$ and current depth of cut is d_e.

For cost $C_{(4,2)}$ current outer diameter is $(D_o - 2d_e)$ and current depth of cut is $2d_e$.

For cost $C_{(4,3)}$ current outer diameter is $(D_o - 2d_e)$ and current depth of cut is $3d_e$.

For cost $C_{(3,1)}$ current outer diameter is $(D_o - 4d_e)$ and current depth of cut is d_e.

For cost $C_{(3,2)}$ current outer diameter is $(D_o - 4d_e)$ and current depth of cut is $2d_e$.

For cost $C_{(3,3)}$ current outer diameter is $(D_o - 4d_e)$ and current depth of cut is $3d_e$.

For cost $C_{(2,1)}$ current outer diameter is $(D_o - 6d_e)$ and current depth of cut is d_e.

For cost $C_{(2,1)}$ current outer diameter is $(D_o - 6d_e)$ and current depth of cut is $2d_e$.

For cost $C_{(1,1)}$ current outer diameter is $(D_o - 8d_e)$ and current depth of cut is d_e.

Different values of feed as defined by various constraints are determined as:

From Eq. (2.15)

$$f_1 = f_{\max} ,$$

From Eq. (2.8)

$$f_2 = \sqrt{8rh_{\max}} ,$$

From Eq. (2.11)

$$f_3 = \left[\frac{F_{\max}}{K_1 d_c^{\,p_2}}\right]^{1/p_1} ,$$

From Eq. (2.19)

$$f_4 = \left[\frac{d_T E D_c^{\,4}}{2K_b K_1 d_c^{\,p_2} L^3}\right]^{1/p_1} ,$$

and from Eq. (2.21)

$$f_5 = \left[\frac{F_L}{0.4K_1 d_c^{\,p_2}}\right]^{1/p_1},$$

Now the feasible range of feed is found out from these values

$f' = MINIMUM(f_1, f_2, f_3, f_4, f_5)$.

where $f_{min.}$ is the minimum feed

Now feed range is $f_{min} \le f \le f'$ and speed range is $V_{min.} \le V \le V_{max.}$

After the feasible range of speed and feed is found out from the constraints, from Eqs. (2.5) and (2.6) the values of $X_c(v,f)$ and $X_t(v,f)$ have been compared for each incremental value of speed and feed to determine the minimum value of the production cost and production time. After minimum value of $X_c(v,f)$ and $X_t(v,f)$ is found out it is stored in a matrix for particular elemental place. These values have been compared by the same program to select the optimum one for which the optimum production cost have been finally calculated. The minimum value of production cost and production time in each possible way Fig.2.2 is shown by this matrix.

$$C_{(i,j)} = \begin{bmatrix} C_{(1,1)} & 0 & 0 & 0 & 0 \\ C_{(2,1)} & C_{(2,2)} & 0 & 0 & 0 \\ C_{(3,1)} & C_{(3,2)} & C_{(3,3)} & 0 & 0 \\ C_{(4,1)} & C_{(4,2)} & C_{(4,3)} & 0 & 0 \\ C_{(5,1)} & C_{(5,2)} & C_{(5,3)} & 0 & 0 \end{bmatrix}$$

where i is initial position q is final position and j=i-q,

$C_{(i,j)}$ is cost in machining from i position to q position.

For example in Fig.2.3:

for $C_{(5,1)}$ initial position i=5 and the final position q=4.

To find out the total production cost, $C_{(i,j)}$ was added in each possible ways Fig.2.3. In the example, maximum depth of cut per pass is 3 mm that indicates M=3. Hence, maximum number of elements can be chosen at a time for turning operation equal to three (M=3), as shown in Fig.2.3. Our starting point is i =5, shown in Fig.2.3. Any cost can be chosen from these three costs $(C_{(5,1)}, C_{(5,2)}, C_{(5,3)})$ to calculate the minimum total cost, as described below.

Let us take $C_{(5,2)}$ then next is in row 5-2 = 3^{rd} row in Fig.2.3

In 3^{rd} row, we can take three options $(C_{(3,1)}, C_{(3,2)}, C_{(3,3)})$.

Let we take $C_{(3,1)}$ then next row 3-1=2^{nd} row in Fig.2.3,

in 2^{nd} row, we can take two options $(C_{(2,1)}, C_{(2,2)})$.

Let us take $C_{(2,2)}$,

(when i=j) then end of summation will take place.

Total cost=$C_{(5,2)} + C_{(3,1)} + C_{(2,2)}$.

Hence like this many options can take place. Now we will compare all options by program and the option that will give total minimum cost will give the result.

$C_{(i,j)}$ can be written as C[i][j].

Total Cost, C=C[N][a]+C[N-a][b]+C[N-a-b][c]+ - - - - - - - - - - - - - - C[p'][p]

When p'=p then end of summation will take place.

$(1 \leq a \leq M)$

$(1 \leq b \leq M)$

$(1 \leq c \leq M)$

Here M=3

Number of option for taking total cost in fifth row in matrix are 3.

Number of option for taking total cost in fourth row in matrix are 3.

Number of option for taking total cost in third row in matrix are 3.

Number of option for taking total cost in second row in matrix are 2.

Number of option for taking total cost in first row in matrix is 1.

Total option will be $3 \times 3 \times 3 \times 2 \times 1 = 54$

Compare all these costs from the above option to find out the minimum cost.

Let final minimum total cost C=C[5][2]+C[3][2]+C[1][1]

Then

In First pass

Depth of cut $=2.d_e$

$=2$mm,

feed=f[5][2],

Speed=v[5][2]

In Second pass

Depth of cut in second pass $=2.\ d_e$

$=2$mm,

feed=f[3][2],

Speed=v[3][2]

In Third pass

Depth of cut $=1.\ d_e$

$=1$mm,

feed=f[1][1],

Speed=v[1][1]

Hence we can find out the total minimum cost for any value of N. If we increase the value of N then the accuracy of the result will be increased.

CHAPTER 3

EXPERIMENTAL SETUP AND PROCEDURE

3.1 Experimental Set-Up:

Experiments were carried out in two stages, 1 and 2. In stage 1, experiments were conducted to determine the coefficients in tool life equation Eq.(2.4) and force equation Eq.(2.10). In stage 2, we validate experimental results with the result obtained by computer programming.

In these experiments, speed, feed and depth of cut were taken as independent variables and cutting force and tool life (tool failure time) as output parameters. Cutting force was measured by kristlar dynamometer. Fig.3.1 shows schematic diagram of the dynamometer. This dynamometer converted cutting force to an equivalent electrical signal, which was amplified by the control unit and measured by a pen recorder. Tool life or tool failure time is measured by a stopwatch. Cutting force directly depends upon flank wear, which in turn depends upon cutting time as shown in Fig.3.2.

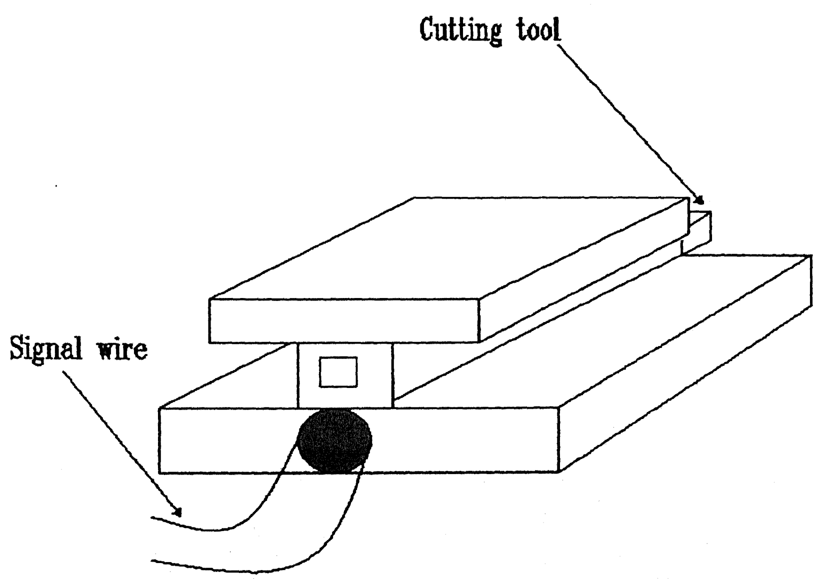


Fig.3.1: Schematic diagram of dynamometer

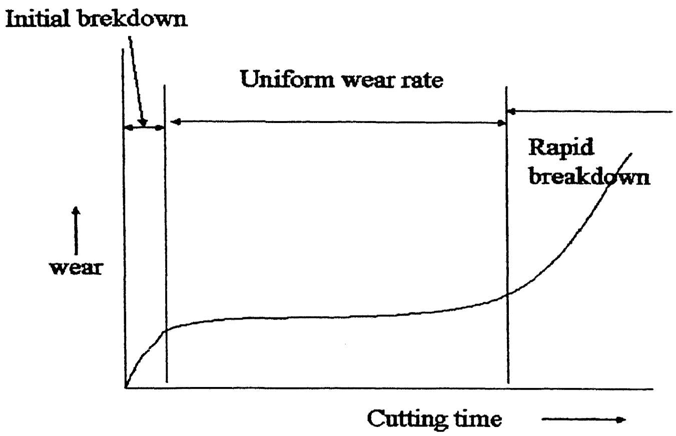


Fig.3.2: Wear land growth

Rapid increase in tool flank wear causes the cutting force to increase rapidly and the tool ultimately breaks down. This rapid increase in cutting force is indicated by the pen recorder, which is identified as the tool failure point and measured by a stopwatch.

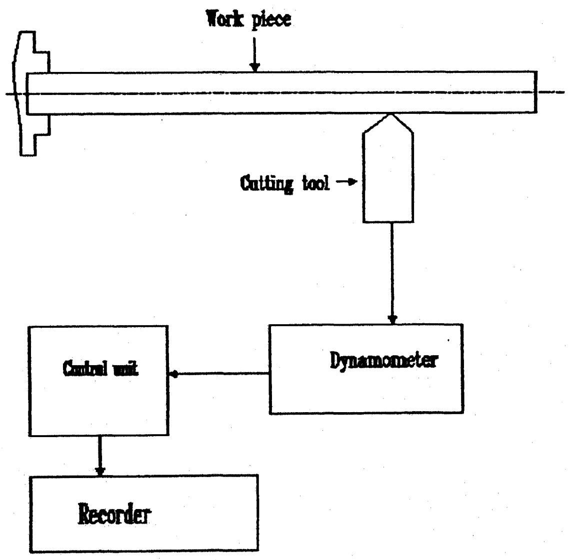


Fig.3.3: Schematic diagram of the experimental setup

A schematic diagram of the experimental setup is shown in the Fig.3.3. Photographs in Fig.3.4, Fig.3.5 and Fig.3.6 show the experimental setup in two different views.

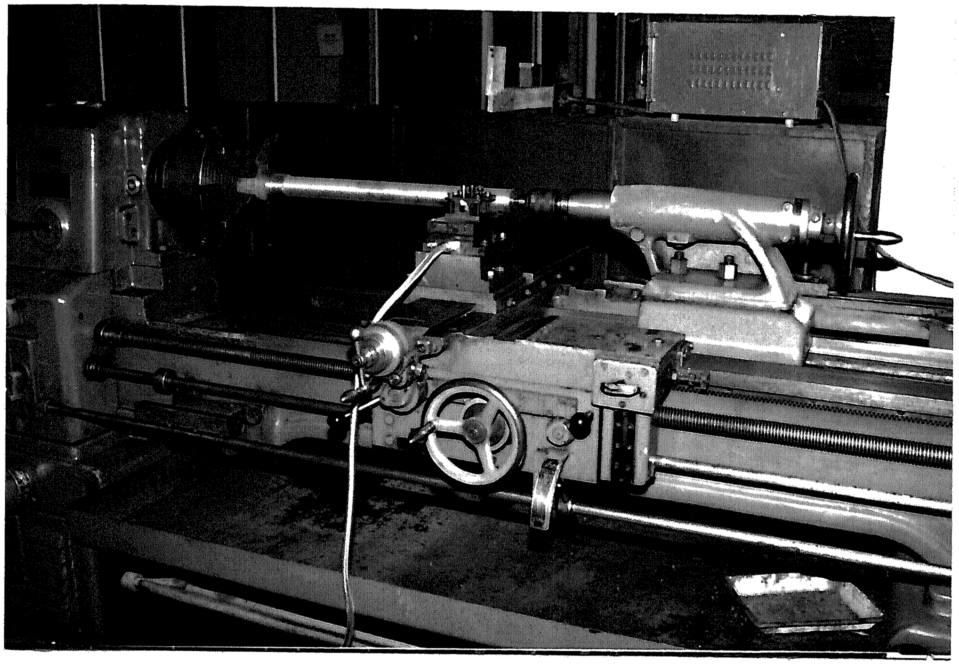


Fig. 3.4 Photograph-1: Experimental set-up

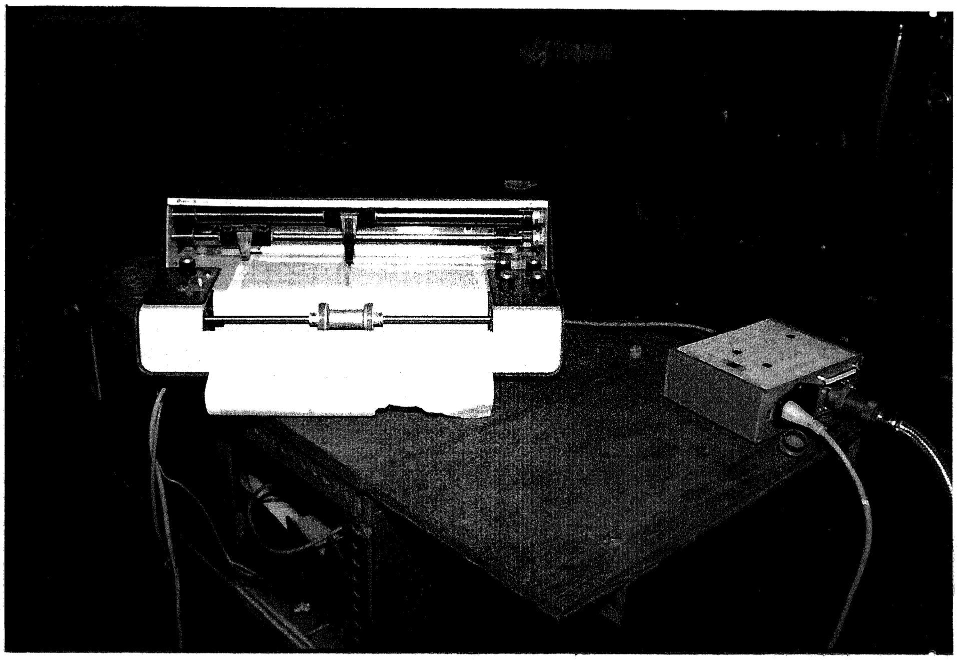


Fig. 3.5 Photograph-2: Experimental set-up

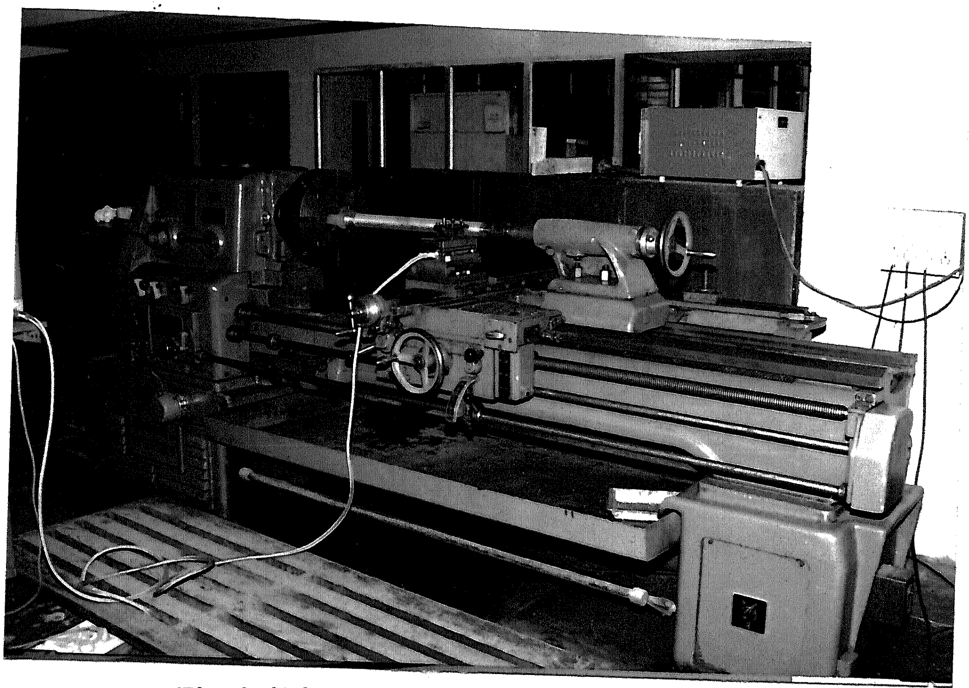


Fig. 3.6 Photograph-3: Experimental set-up

3.2 Experimental Procedure

3.2.1 2^k Factorial Design For Three Factors

Experimental procedure was based on design of experiment 2^k factorial design for three factors were used in the experiment. Input parameters were varied as shown in table 3.1. 2^k factorial design is the most widely used factorial design having two levels for each of 'k' factors. The two levels of factors are referred to as low (-), and high (+). If there are three factors say A, B and C, under study and each factor is at two levels arranged in a factorial experiment, then, this constitutes a *2^3 factorial design.*

The 8 treatment combinations in the design of experiments have 7 degrees of freedom. Each individual parametrical effect has two degrees of freedom and each two-factor interaction has 4 degrees of freedom. If there are n replicates, then there will be $(n \times 2^3 - 1)$ degrees of freedom and $2^3(n\text{-}1)$ degrees of freedom for error. In the present

experimental work, there are 3 input variables, e.g. namely cutting speed, feed and depth of cut. Ranges of these parameters were decided on the basis of handbooks [22].

Levels of the process variables (speed, feed and depth of cut) are shown in table 3.1. The range of input parameters, e.g. speed, feed, and depth of cut was determined based on the machine capabilities, handbook and experience as:

Cutting speed (V): 22 to 31 m/min.
Feed (*f*) : 0.15 to 0.3 mm/rev.
Depth of cut (*d*) : 0.5 to 1.0 mm.

	Input variables		
Experiment No.	Speed V (m/min.)	Feed *f* (mm/rev.)	Depth of cut *d* (mm)
1	-	-	-
2	-	+	-
3	-	-	+
4	-	+	+
5	+	-	-
6	+	+	-
7	+	-	+
8	+	+	+

Table 3.1: Levels of the process variables in different experiments

3.2.2 Method Of Finding Out Coefficient Such as $\alpha, \beta, \gamma, K_e$

The values of $\alpha, \beta, \gamma, K_e$ were found out by least square method

From Eq(2.4)

$$T = \frac{K_e}{v^{\alpha} f^{\beta} d^{\gamma}},$$

or,

$$\ln(T) = K_e - \alpha \ln(v) - \beta \ln(f) - \gamma \ln(d). \quad (3.1)$$

It is assumed that for each observation ln(*T*) can be described by the model as:

$$\ln(T) = K_e - \alpha \ln(v) - \beta \ln(f) - \gamma \ln(d) + \varepsilon, \quad (3.2)$$

Where ε is a random error with mean zero and variance, σ^2, and

$$\varepsilon = \ln(T) - K_e + \alpha \ln(v) + \beta \ln(f) + \gamma \ln(d). \quad (3.3)$$

If 'n' number of data points is obtained through experimentation, then $\alpha,\ \beta,\ \gamma$ and K_e can be estimated by least squares. The least square function is

$$L=\sum_{j=1}^{n}\varepsilon_j^2=\sum_{j=1}^{n}[\ln(T)-K_e+\alpha\ln(v)+\beta\ln(f)+\gamma\ln(d)\ ]^2\ . \tag{3.4}$$

Minimization of least squares is simplified if the model is rewritten as:

$$\ln(T)=K_e-\alpha\ln(v-\bar{v})-\beta\ln(f-\bar{f})-\gamma\ln(d-\bar{d})+\varepsilon\ , \tag{3.5}$$

where,

$$\bar{v}=(\frac{1}{n})\sum\nolimits_{j=1}^{n}v_j$$

$$\bar{f}=(\frac{1}{n})\sum\nolimits_{j=1}^{n}f_j$$

$$\bar{d}=(\frac{1}{n})\sum\nolimits_{j=1}^{n}d_j$$

Thus least squares function becomes

$$L=\sum_{j=1}^{n}\varepsilon_j^2=\sum_{j=1}^{n}[\ln(T)-K_e+\alpha\ln(v-\bar{v})+\beta\ln(f-\bar{f})+\gamma\ln(d-\bar{d})\ ]^2\ , \tag{3.6}$$

$$\frac{\partial L}{\partial K_e}=0\ ,$$

$$-2.\sum_{j=1}^{n}[\ln(T)-K_e+\alpha\ln(v-\bar{v})+\beta\ln(f-\bar{f})+\gamma\ln(d-\bar{d})\ ][1]=0\ , \tag{3.7}$$

$$\frac{\partial L}{\partial \alpha}=0\ ,$$

$$2.\sum_{j=1}^{n}[\ln(T)-K_e+\alpha\ln(v-\bar{v})+\beta\ln(f-\bar{f})+\gamma\ln(d-\bar{d})\ ][\ln(v-\bar{v})]=0 \tag{3.8}$$

$$\frac{\partial L}{\partial \beta}=0\ ,$$

$$2.\sum_{j=1}^{n}[\ln(T)-K_e+\alpha\ln(v-\bar{v})+\beta\ln(f-\bar{f})+\gamma\ln(d-\bar{d})\ ][\ln(f-\bar{f})]=0\ , \tag{3.9}$$

$$\frac{\partial L}{\partial \gamma} = 0,$$

$$2.\sum_{j=1}^{n}[\ln(T) - K_e + \alpha\ln(v-\bar{v}) + \beta\ln(f-\bar{f}) + \gamma\ln(d-\bar{d})][\ln(d-\bar{d})] = 0 \cdot \qquad (3.10)$$

From these four Eqs.(3.7), (3.8), (3.9) and (3.10) values of $\alpha, \beta, \gamma, K_e$ can be easily determined.

Similarly the values of p_1 and p_2 for force equation can be found out from Eq(2.10).

The purpose of the experiment in stage 2 was to validate production cost determined experimentally with production cost obtained by computer programming. From program, the minimum production cost, total number of passes, speed, feed, depth of cut and production cost in each pass have been found out.

The Eqs. (2.1) and (2.2) were used for production cost and production time respectively. In both equations machining time (T_m) and tool life (*T*) are variables, and all others are constants. Constants were taken from annexure-1 and were put in Eqs. (2.1) and (2.2). Machining time (T_m) was found out by experimentally at the speed, feed and depth of cut obtained from program. Tool life was found out by tool life Eq.(2.4) at the speed, feed and depth of cut obtained from program. The values of machining time (T_m) and tool life (*T*) were put in Eqs. (2.1) and (2.2) and Production cost and production time was found out.

Production cost and production time for first, second and third pass was found out. This production cost and production time was found out experimentally and comparison was made with the values found out by program.

RESULT AND DISCUSSION

4.1 Results Obtained From Stage 1 Experiments For Finding Out Coefficients Such As α, β, γ, p_1 And p_2

Table 4.1 depicts the values of experimentally measured output parameters for a particular combination of input variables in eight experiments as per DOE. Substituting the values of speed, feed depth of cut and tool life as well as cutting force for each experiment as mentioned in Table 4.1, in Eq.(2.4) and (2.10), eight equation were obtained which were solved simultaneously to obtain the values of coefficients as mentioned below.

Input variables			Measured output parameters	
Speed v(m/min.)	feed f(mm/rev.)	Depth of cut d(mm)	Tool Life (T) min	Cutting Force (F_c) N
22	0.15	0.5	23.5	179.5
22	0.3	0.5	17.5	315.0
22	0.15	1.0	13.5	342.0
22	0.3	1.0	18.8	599.5
31	0.15	0.5	8.8	181.5
31	0.3	0.5	6.4	319.0
31	0.15	1.0	7.0	344.5
31	0.3	1.0	5.0	602.5

Table 4.1: Table of experimental result obtained from experiments.

Final values of $(\alpha, \beta, \gamma, K_e)$ are

$\alpha = 2.9$

$\beta = 0.47$

$\gamma = 0.33$

$K_e = 6.1 \times 10^4$

Graphs were plotted after substituting these coefficients in Eq.(2.4) to show the variation of tool life with speed, feed and depth of cut. These graphs are shown in Fig. 4.1-4.3.
Similarly for cutting force, the coefficients of Eq.(2.10) were found as:

$K_1 = 159.0$

$p_1 = 0.81$

$p_2 = 0.93$

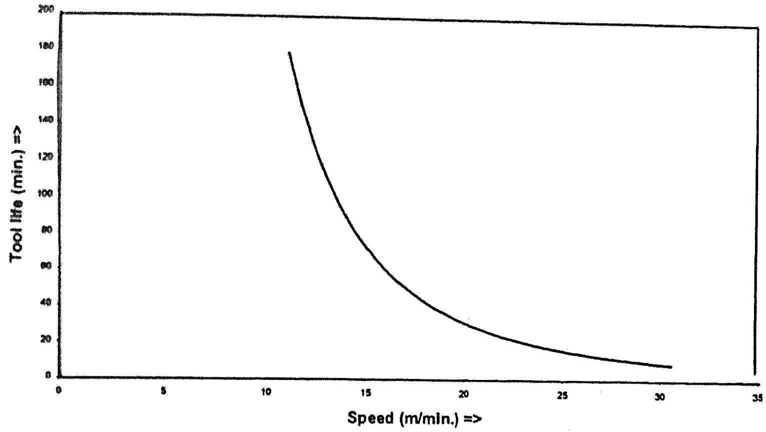


Fig.4.1: Variation of tool life with speed. (Feed = 0.15 mm/rev. and depth of cut = 0.50 mm.)

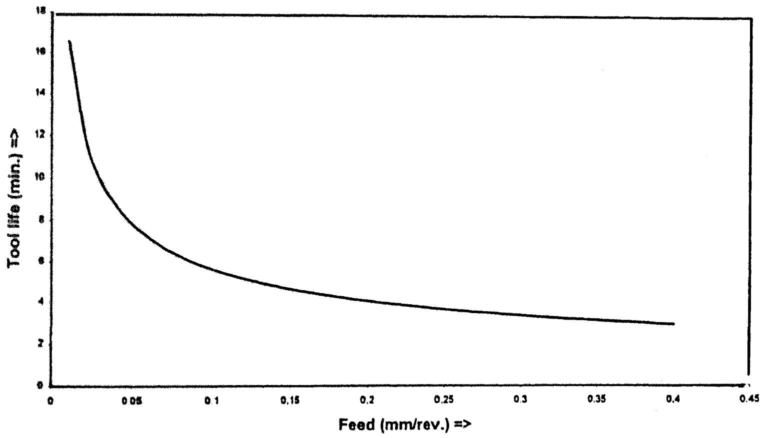


Fig.4.2: Variation of tool life with feed. (Speed = 22 m/min. and depth of cut = 0.5 mm.)

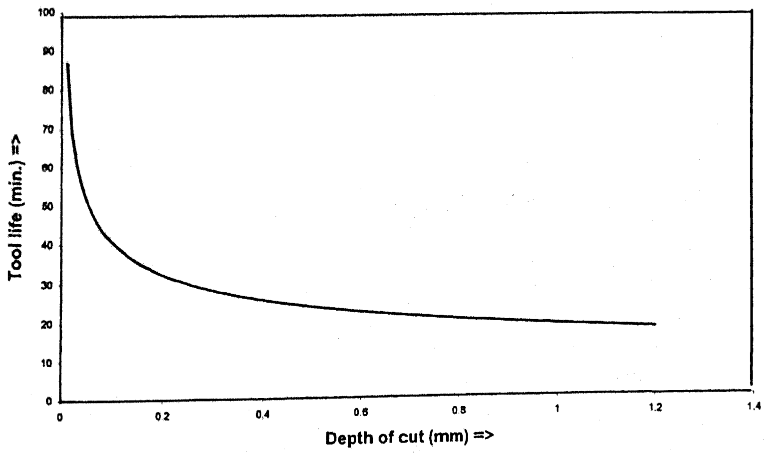


Fig.4.3: Variation of tool life with depth of cut. (Speed = 22 m/min. and feed = 0.15 mm/rev.)

Graphs were plotted after substituting these coefficients in Eq (2.10) to show the variation of cutting force with feed and depth of cut. These graphs are shown in Fig. 4.4-4.5.

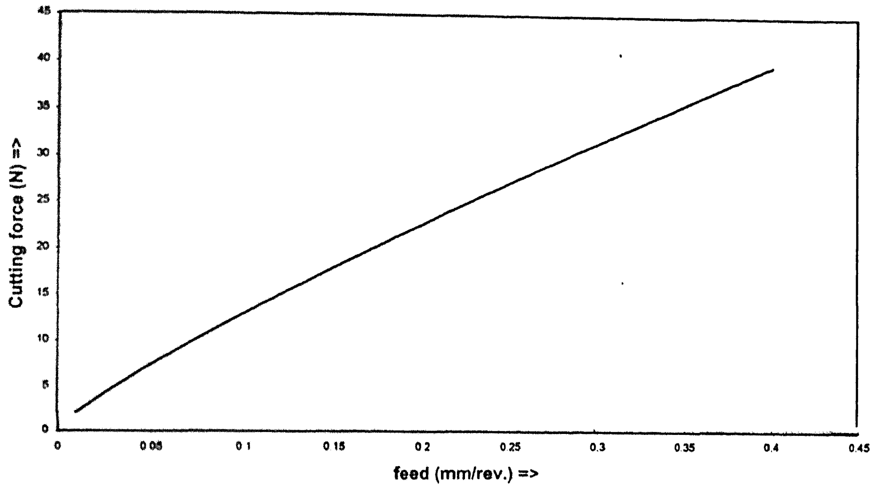


Fig.4.4: Variation of cutting force with feed. (depth of cut = 0.5 mm.)

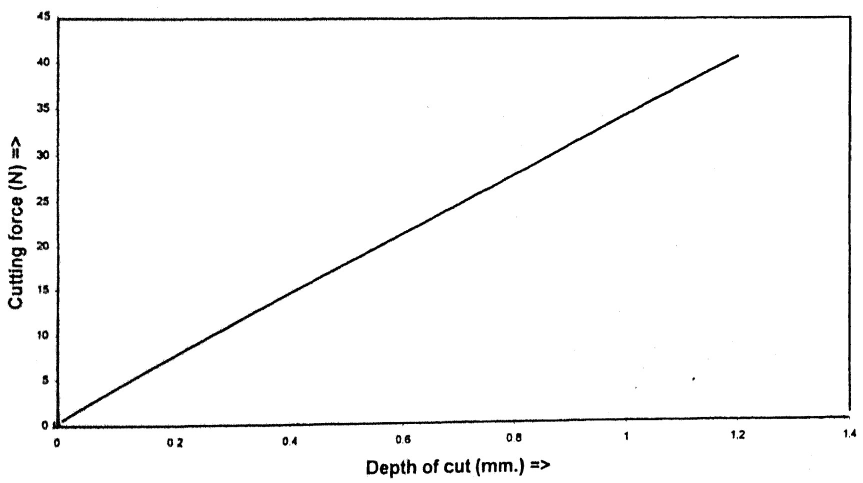


Fig.4.5: Variation of cutting force with depth of cut. (feed = 0.15 mm/rev.)

Graphs were plotted after substituting these coefficients in Eq (2.10) to show the variation of cutting force with feed and depth of cut. These graphs are shown in Fig. 4.4-4.5.

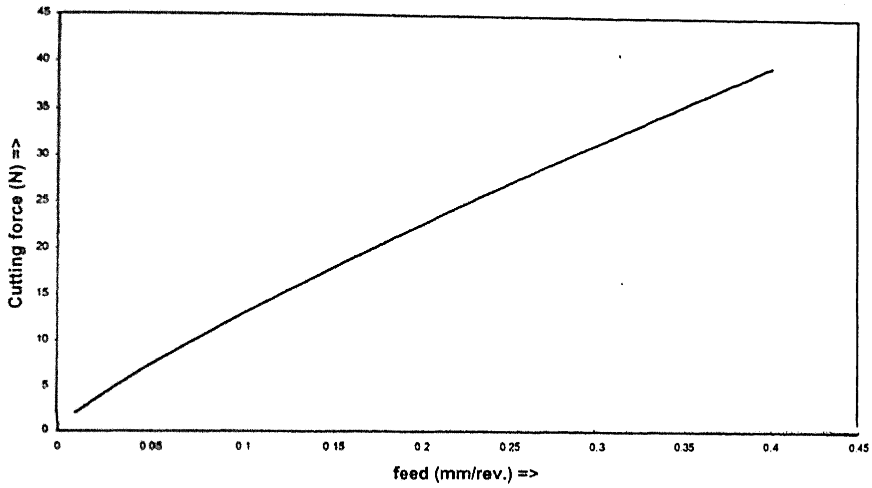


Fig.4.4: Variation of cutting force with feed. (depth of cut = 0.5 mm.)

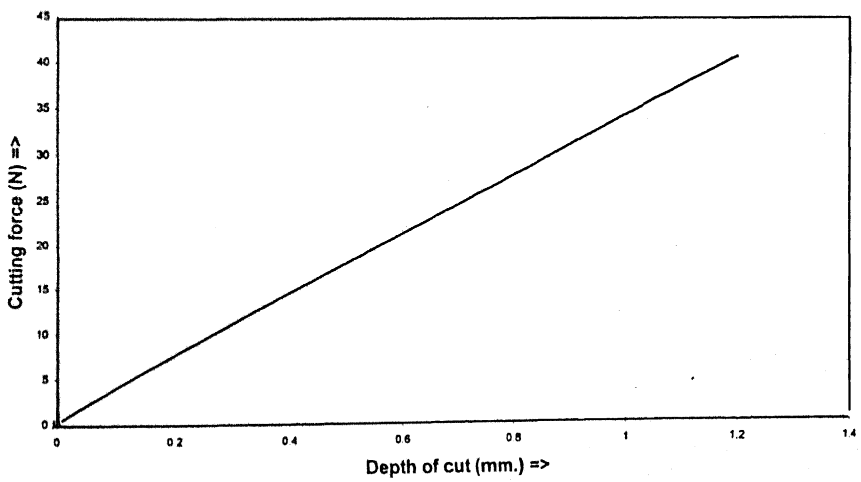


Fig.4.5: Variation of cutting force with depth of cut. (feed = 0.15 mm/rev.)

Production Cost And Time By Program

In Table 4.2 shows the time taken in machining and tool life with speed, feed and depth of cut for production cost. Values of speed, feed and depth of cut comes from program in this table. Tool life was find out Substituting these values (V, *f* and *d*) in Eq.(2.4) and machining time was find out by experiments by a stopwatch.

No of passes	Speed(m/min.)	Feed(mm/rev.)	Depth of cut(mm)	Time taken in machining from experiments(min.)	Tool life (min.)
First pass	21.5	0.26	0.75	22.14	17.3
Second pass	22.0	0.23	0.75	19.7	17.1
Third pass	23.0	0.14	1.00	29.53	17.3

Table 4.2: Time taken in machining and tool life with speed, feed and depth of cut for production cost

From this data we can find out cost from experiments in every pass to using Eq. (2.1). For a very large batch size (N_s) the term $\frac{C_j + C_o T_s}{N_s}$ can be neglected.

Production cost for first pass $= 0 + 5.(2+2) + 5.(22.14) + (5 \times 2 + 35).\frac{22.14}{17.3}$

=144.025 Rs.

Production cost for second pass $= 0 + 5.(2+2) + 5.(19.7) + (5 \times 2 + 35).\frac{19.7}{17.1}$

=170.150 Rs.

Production cost for third pass $= 0 + 5.(2+2) + 5.(29.53) + (5 \times 2 + 35).\frac{29.53}{17.3}$

=244.500 Rs.

Cost from program comes for minimization of total cost

Cost for first pass=159.19

Cost for second pass=170.4

Cost for third pass=249.5265

Table 4.3 shows comparison of production cost using experimental data and the one obtained from computer program is close to the production cost using experimental data.

No of passes	Speed (m/min.)	Feed (mm/rev.)	Depth of cut (mm)	Cost from program (Rs.)	Cost from experiments (Rs.)
First pass	21.5	0.26	0.75	159.19	144.025
Second pass	22.0	0.23	0.75	170.4	170.150
Third pass	23.0	0.14	1.00	249.5265	244.500
				Total Cost=579.12	Total Cost=558.675

Table 4.3: Comparison of Cost Experimental values with the program values

Values of input parameters (V, *f* and *d*) from Table 4.3 for each pass have been substituted along with values of constants (see Annexure-1) in the Eq. (2.5). This equation was solved by the computer program to reveal the relationship between the production cost and the input parameters within their range. These 3-dimensional curves are shown in Fig 4.6-4.8 for three passes. The minimum production cost calculated by the computer program has been shown as a (*) in these curves. The values of speed and feed for this point of minimum production cost have been indicated in each of these figures

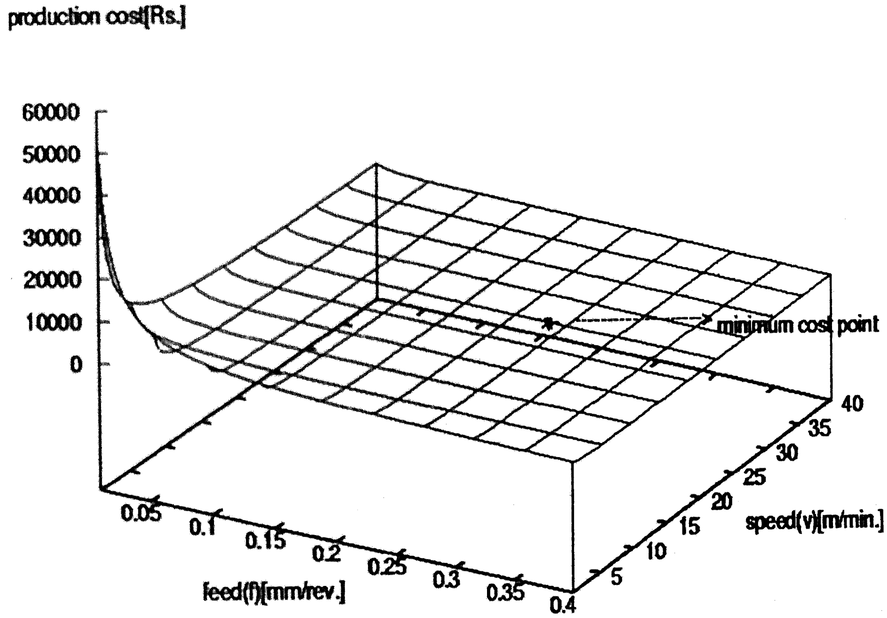


Fig.4.6: Shows minimum cost point for first pass
[speed=21.5m/min., feed=0.26mm/rev. and minimum cost=159.19(Rs.)]

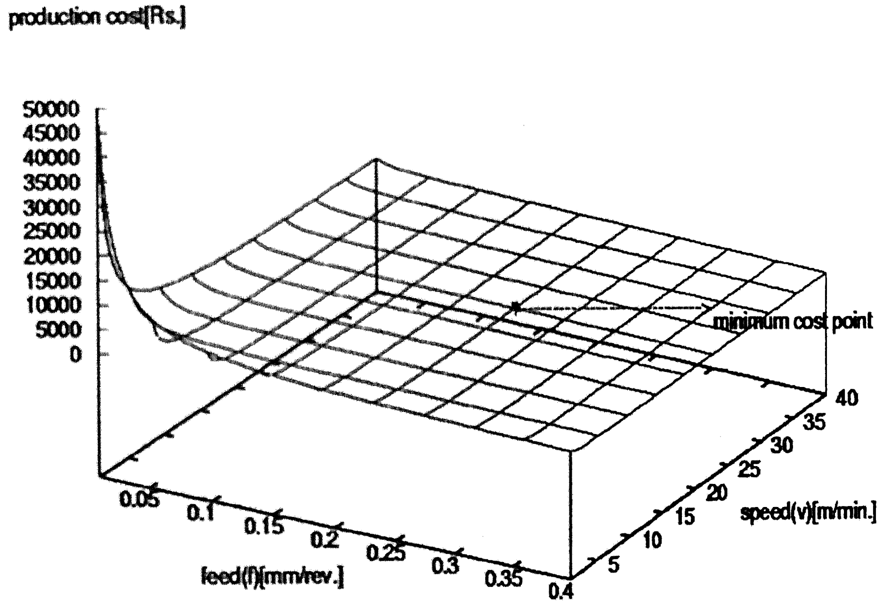


Fig.4.7: Shows minimum cost point for second pass
[speed=22m/min., feed=0.23mm/rev.and minimum cost=170.40(Rs.)]

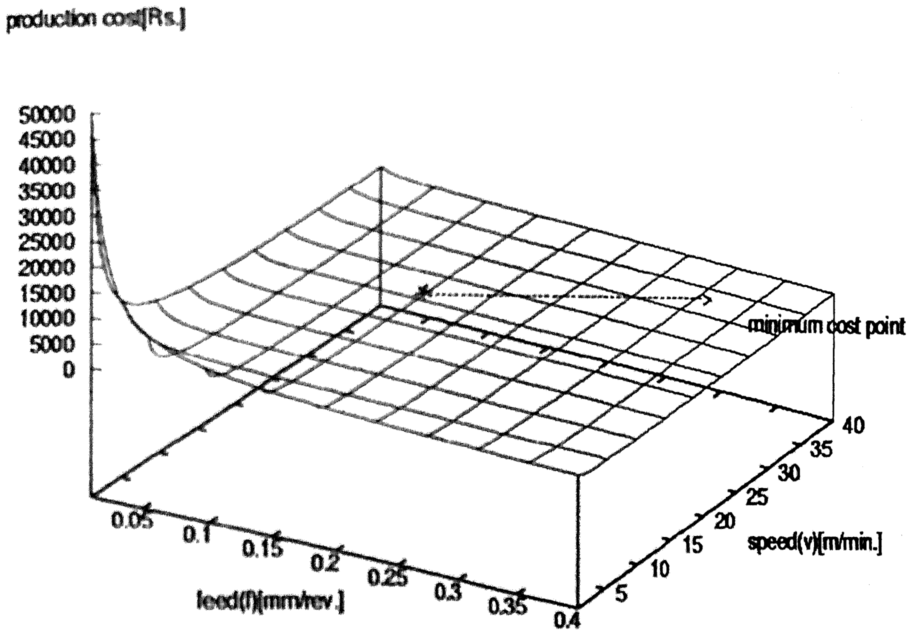


Fig.4.8: Shows minimum cost point for third pass
speed=23m/min., feed=0.14mm/rev.and minimum cost=249.53(Rs.)]

In Table 4.4 shows the time taken in machining and tool life with speed, feed and depth cut for production time. Values of speed, feed and depth of cut comes from program in this le. Tool life was find out Substituting these values (V, f and d) in Eq. (2.4) and machining e was find out by experiments by a stopwatch.

of sses	Speed	Feed	Depth of cut	Time taken in machining from experiments (min.)	Tool life (Min.)
st pass	27.0	0.14	0.875	24.1	11.3
cond pass	26.5	0.12	0.875	28.30	12.8
ird pass	26.0	0.12	0.75	28.11	14.3

ble 4.4: Time taken in machining and tool life with speed, feed and depth of cut for oduction time

om this data we can find out production time from experiments in every pass to using Eq. .2).

or a very large batch size (N_s) the term $\frac{T_s}{N_s}$ can be neglected.

roduction for first pass $= 0+(2+2)+(24.1)+2.(\frac{24.1}{11.3})$

$=32.36$ Min.

roduction time for second pass $= 0+(2+2)+(28.3)+2.(\frac{28.3}{12.8})$

$=36.725$ Min.

roduction time for third pass $= 0+(2+2)+(28.113)+2.(\frac{28.113}{14.3})$

$=36.045$ Min.

able 4.5 shows Comparison of production time Experimental values with the program values. roduction time from program is close with the production time from experiments. Speed, feed nd depth of cut is comes from program and cost from experiment find out from experiment in bove.

In Table 4.4 shows the time taken in machining and tool life with speed, feed and depth of cut for production time. Values of speed, feed and depth of cut comes from program in this table. Tool life was find out Substituting these values (V, f and d) in Eq. (2.4) and machining time was find out by experiments by a stopwatch.

No of passes	Speed	Feed	Depth of cut	Time taken in machining from experiments (min.)	Tool life (Min.)
First pass	27.0	0.14	0.875	24.1	11.3
Second pass	26.5	0.12	0.875	28.30	12.8
Third pass	26.0	0.12	0.75	28.11	14.3

Table 4.4: Time taken in machining and tool life with speed, feed and depth of cut for production time

From this data we can find out production time from experiments in every pass to using Eq. (2.2).

For a very large batch size (N_s) the term $\frac{T_s}{N_s}$ can be neglected.

Production for first pass = $0+(2+2)+(24.1)+2.(\frac{24.1}{11.3})$

=32.36 Min.

Production time for second pass = $0+(2+2)+(28.3)+2.(\frac{28.3}{12.8})$

=36.725 Min.

Production time for third pass = $0+(2+2)+(28.113)+2.(\frac{28.113}{14.3})$

=36.045 Min.

Table 4.5 shows Comparison of production time Experimental values with the program values. Production time from program is close with the production time from experiments. Speed, feed and depth of cut is comes from program and cost from experiment find out from experiment in above.

No of passes	Speed	Feed	Depth of cut	Time from program (Min.)	Time from experiments (Min.)
First pass	27.0	0.14	0.875	34.465	32.36
Second pass	26.5	0.12	0.875	38.11	36.725
Third pass	26.0	0.12	0.75	36.796	36.045
				Total Time=109.372	Total Time=105.13

Table 4.5: Comparison of Time Experimental values with the program values

Values of input parameters (V, f and d) from Table 4.3 for each pass have been substituted along with values of constants (see Annexure-1) in the Eq. (2.5). This equation was solved by the computer program to reveal the relationship between the production time and the input parameters within their range. These 3-dimensional curves are shown in Fig 4.5-4.7 for three passes. The minimum production time calculated by the computer program has been shown as a (*) in these curves. The values of speed and feed for this point of minimum production time have been indicated in each of these figures.

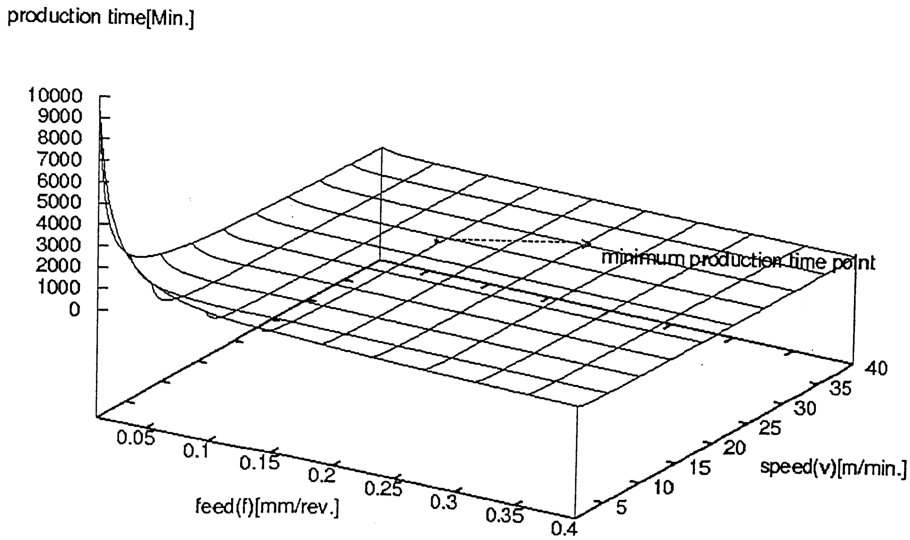


Fig 4.9: Shows minimum production time point for first pass (speed=27m/min, feed=0.14mm/rev.and minimum time=34.465min.)

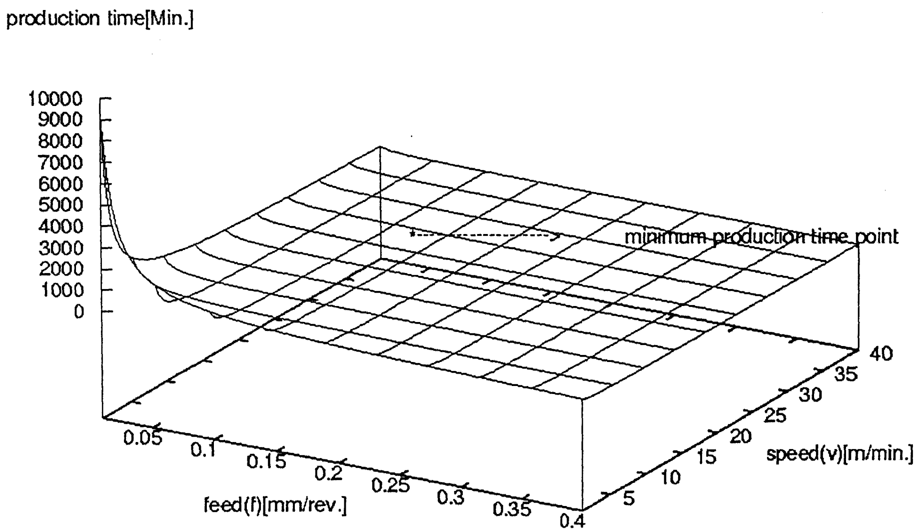


Fig 4.10: Shows minimum production time point for second pass (speed=26.5m/min., feed=0.12mm/rev. and minimum time=38.11min.)

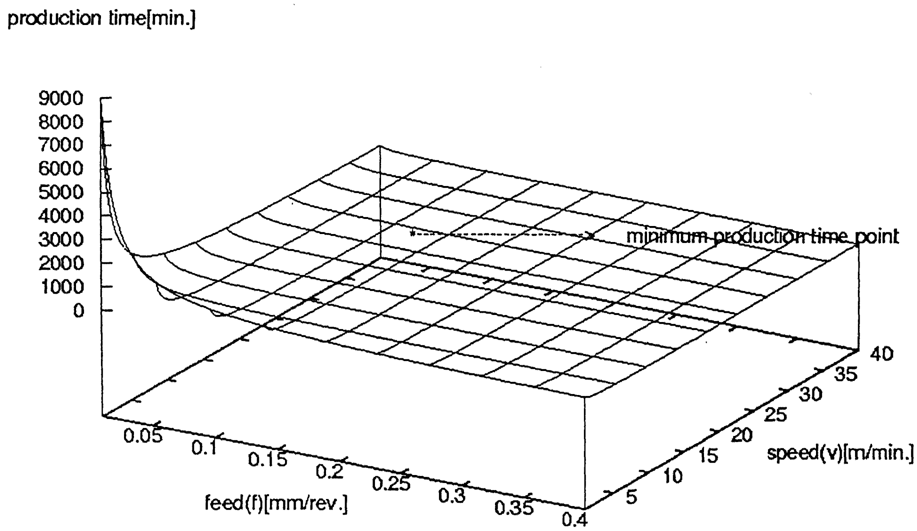


Fig 4.11: Shows minimum production time point for third pass

(speed=26m/min., feed=0.12mm/rev. and minimum time=36.045min.)

4.3 Comparison Of Experimental Result To Program

	Production Cost from experiments	Production Cost from program	Error in (%)	Production time from experiments	Production time from program	Error in (%)
First pass	144.025	159.190	9.53	32.360	34.465	6.10
Second Pass	170.150	170.400	0.15	36.725	38.110	3.63
Third pass	244.500	249.530	2.01	36.045	36.796	2.04
Total	558.675	579.120	3.53	105.130	109.371	3.88

Table 4.6: Comparison of Experimental values (Production cost and production time) with the program values (Production cost and production time) .

Table 4.6 shows comparison of experimental values (Production cost and production time) with the program values (Production cost and production time) percentage error in total minimum cost by programmed value and experimental value is 3.53 And percentage error in total minimum time by programmed value and experimental value is 3.88 hence both experimental result is nearer with the programmed value.

CHAPTER 5
CONCLUSION AND SCOPE FOR FUTURE WORK

This work presents a model of optimizing machining conditions under the minimum production cost and minimum production time criteria and machining constraints for multi pass turning operations. The optimization procedure is achieved by a computer programming technique which has a mathematical model of dynamic programming for multi pass machining process and the optimization of each stage was accomplished through the feasible region in the feed and velocity region All constraints that act on turning operations are considered in the computer programming.

Although in machining, 5% CO HSS tools and EN24 work piece material were used in the experiments, it is possible to determine the optimum cutting conditions for work piece and tool combination with graphical representation. This method is also suited to the optimization of other multi pass machining operations. The optimization procedure can be adopted to milling or drilling operations by changing the coefficients of objective factors and constraints.

In the present work first, experiments had been done for all coefficients. Cutting force coefficient, tool life coefficient, tool life exponents and cutting forcc exponents are found out from these experiments and after that second experiments had been done for a validation of optimum result.

Scope For Future Work

FEM technique may be used in present work. The present work may be easily extended to obtain optimal machining conditions for plane and face milling operations by changing the coefficients of objective function and constraints. Some constraints may be added like temperature at tool chip interface, torque, and tensile stress on rake face, primary shear zone temperature and surface integrity etc. Machine available speed also may be input in the present work but this technique can not generalized it will be advantageous only for industrial label because every machine have different machining speed

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ANNEXURE-1

Level designation of different process variables

• Workpiece material	:	EN 24 steel
• Workpiece composition	:	0.35 – 0.45 % C; 0.45 – 0.6 % Mn; 1.3 – 1.8 % Ni; 0.9 – 1.4 % Co; 0.2 – 0.3 % Cr; 0.1 – 0.35 % Si; Rest is Iron.
• Workpiece hardness	:	260 BHN
• Cutting tool material	:	HSS with 5 % Cobalt
• Cutting tool composition	:	18 % W, 4 % Cr, 2 %V, 5 % Co
• Tool geometry	:	0°-11°-6°-6°-12°-15°-1.5 mm (ASA)
• Speed range	:	32 - 640 RPM
• Specification of lathe	:	Turning Lethe, Type: LB 25 Center height: 250 mm Center distance: 1500 mm Swing over bed: 500 mm Swing over cross slide: 330 mm Spindle speeds: 32-640 RPM Feeds: 0.03-1.4 mm/rev.

Data used for machining EN24 work piece material with HSS tool [23].

- Initial diameter of work determination of production cost = 60 mm
- Initial diameter of work piece determination of production time = 55 mm
- Length of work piece = 540 mm
- Total depth of cut = 2.5mm
- Allowable cutting speed range $V_{min.} = 5$m/min.; $V_{max.} =$ 37m/min.
- Allowable cutting feed range $f_{min.} =$ 0.01mm/rev.; $f_{max.} =$ 0.4mm/rev.
- Constant for tool life equation, $K_e = 6.1 \times 10^4$ (calculated see chapter 4)
- Exponents for tool life equation, $\alpha = 2.9; \beta = 0.47; \gamma = 0.33$ (calculated see chapter 4)
- Constant for cutting force equation, $K_1 = 159$ (calculated see chapter 4)
- Maximum allowable cutting power, $P_{max.} = 5$KW
- Nose radius, r =1.5mm
- Exponents for cutting force equation, $p_1 = 0.81; p_2 = 0.93$ (calculated see chapter 4)
- Maximum surface roughness, $R_{max.} = 0.007mm$
- Maximum force, $F_{max.} = 100N$
- Machine efficiency, $\eta = 0.85$
- Diametrical tolerances, $d_t = 3 \times 10^{-6}$
- Maximum depth of cut per pass = 1mm
- Batch size, $N_s = 9 \times 10^9$
- Cost of labor and overhead, $C_o = 5$Rs.
- Jig and fixture cost, $C_j =$ 4Rs.
- Tool cost, $C_t = 35$Rs./cutting edge
- Tool set up time, $T_S = 2$min.
- Process adjusting and return time, $T_a = 2$min.
- Loading and unloading time, $T_1 = 2$min.

- Tool changing time, $T_c = 2$min.
- Total elements, N = 20
- Radial deflection coefficient, $K_b = 0.6$
- Young modulus of elasticity, E = 2.125×10^{11}
- Coefficient, $F_1 = 23$

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